Monitoring Russian Navigation Satellites

by Brian Webb

Introduction

Few areas of scanning intrigue listeners more than satellite monitoring. Although numerous operational spacecraft circle the earth, most are difficult to hear because they use low transmitter power, transmit outside the frequency ranges of most scanners, or require extended monitoring before one hears anything.

Luckily, there's an exception to this problem: The Russian Low Earth Orbit (LEO) navigation satellites (NAVSATs). For three decades these spacecraft have provided the Russian navy and merchant marine with navigational information. Their powerful VHF and UHF signals are easily heard on even the simplest receiving setups.

Russian LEO NAVSAT Systems

The Russians operate two separate, but complementary LEO NAVSAT systems (Table 1). The first, for military users, is called Parus and consists of six satellites with orbital planes spaced at 30 degree intervals.[1] Civilians, meanwhile, use the Tsikada system, a constellation of four satellites with orbital planes spaced at 45 degree intervals. The orbital planes of the military and civilian systems NAVSATs are positioned opposite to one another, apparently to maximize coverage.[2]

Satellites of both systems follow near-circular, 597x628 mile orbits inclined 82.9 degrees to the equator. The Russians selected this low orbit to reduce the required satellite transmitter power and ground-based receiver sensitivity. The high orbital inclination was chosen to ensure coverage of the entire Russian territory and Arctic Ocean.[3] All of these NAVSATs also have orbital periods of 104.8 minutes.

The military and civilian NAVSATs are also virtually identical in terms of design. All satellites are barrel-shaped (Figure 1) with a latticework and boom protruding from the top. Solar cells mounted around the circumference of the main body provide electrical power. A pressurized vessel containing the spacecraft electronics protrudes from the ends of the body. A flat, disc-shaped antenna on the bottom of each satellite radiates VHF and UHF signals. Some of the civilian NAVSATs also carry antennas and a transponder to receive and relay transmissions from emergency locator beacons.[4]

Theory of Operation

The principle of operation behind these two NAVSAT systems is fairly simple. Each satellite simultaneously transmits time signals and position data on VHF and a dead carrier on UHF (Table

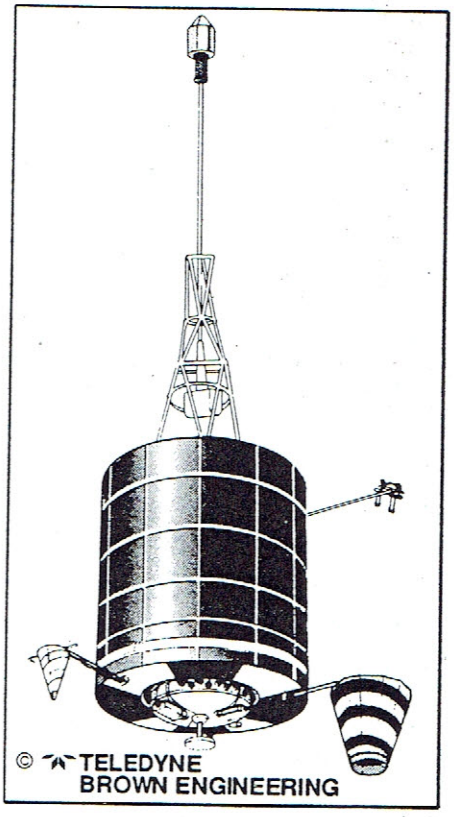

Figure 1. Tsikada navigation satellite. The conical structures are antennas used for the distress beacon transponder. (Illustration by Robert A. Sweeny)

Table 1. Russian LEO NAVSAT Systems.

System Type	Military	Civilian
System Name	Parus	Tsikada
Orbital Plane Spacing (deg.)	30	45
Spacecraft	Kosmos 2184 Kosmos 2218 Kosmos 2233 Kosmos 2239 Kosmos 2266	Kosmos 2230 Nadezhda 3 Nadezhda 4 Tsikada 1 Kosmos 2279

Note: Data is as of February 1, 1995

2). During a satellite pass, the VHF signal is monitored to obtain time versus position data for the spacecraft. The UHF signal, meanwhile, is monitored to determine the NAVSAT's time of closest approach (TCA) to the user. Both signals are observed to correct for ionospheric refraction.[5]

Table 2. Russian LEO NAVSAT Frequency Pairs.

Frequency Pair (MHz)		NAVSAT
VHF	UHF	System
149.910	399.760	Military
149.940	399.840	Military
149.970	399.920	Military
150.000	400.000	Civilian
150.030	400.080	Military

The TCA is found by observing the UHF signal's Doppler shift. When a NAVSAT rises over the user's horizon, the frequency on which the UHF signal is heard is above the actual transmitted frequency. As the satellite approaches the user, the received frequency of the signal drops. For a short instant, at the TCA, the two frequencies match. The received frequency of the UHF signal continues to drop for the remainder of the pass.

The observed TCA and NAVSAT position data are used to determine where the satellite was on its groundtrack at the TCA (Figure 2). This point is called the point of closest approach (PCA). With the PCA located, a line of position (LOP) is established by placing a straight line perpendicular to the groundtrack through the PCA. The user's location is then defined as a an unknown point somewhere along the LOP. A second pass is then observed and the process is repeated. The intersection of the two LOPs is the user's position.[6] Two passes have to be observed to obtain a fix. For maximum accuracy, three or more passes are required.

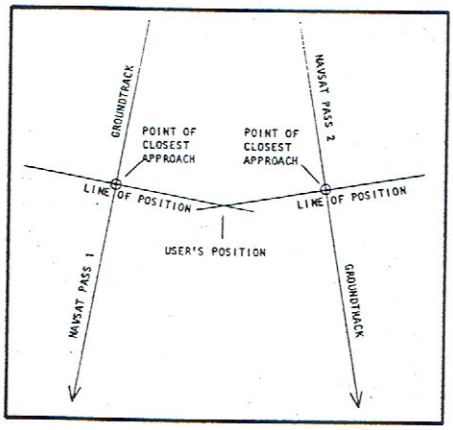

Figure 2. Graphic representation of how a fix is obtained.

The Russians claim that, by using this technique, users can fix their position to within 80 to 100 meters (262 to 328 feet). The weakness of the Parus and Tsikada systems is the limited number of satellites in each constellation. This results in gaps in the coverage and forces the user to wait until at least two passes have been observed before a fix can be obtained.

Signal Characteristics

Each NAVSAT simultaneously transmits a VHF and UHF signal. The VHF transmissions are quite strong and consist of a time pip each second along with data transmitted at 50 baud.[7] The UHF signals, meanwhile, are much weaker and are nothing more than dead carriers. During a pass, both VHF and VHF signals undergo a Doppler shift, with maximum shifts on overhead passes. The maximum observed shifts from the actual transmitted frequencies are approximately +/-5 KHz and +/- 10 KHz for the VHF and UHF signals, respectively. Thus, a 150.000 MHz signal would be heard over a range of frequencies between 149.995 and 150.005 MHz.

Required Equipment

Russian LEO NAVSAT transmissions are strong and occur on frequencies within the tuning

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ranges of most scanners. Thus, they can even be heard on inexpensive receivers with simple antennas. The telescoping whip antennas that come with tabletop scanners are more than adequate for indoor reception of the VHF transmissions. Since the UHF signals are weaker and unmodulated, they're harder to hear (yet still audible) using a whip. Better reception requires the use of a better antenna, such as a discone or groundplane, located outdoors.

A groundplane antenna for NAVSAT reception (Figure 3) can be easily constructed using a flange-type SO-239 UHF bulkhead connector and 3/32-and 1/8-inch diameter brass brazing rod [8] or copper wire. The first step is to cut the brass rod stock to the proper length. Make each element 18 13/16-inches long for VHF or 7 1/16-inches long for UHF monitoring. Insert the 3/32-

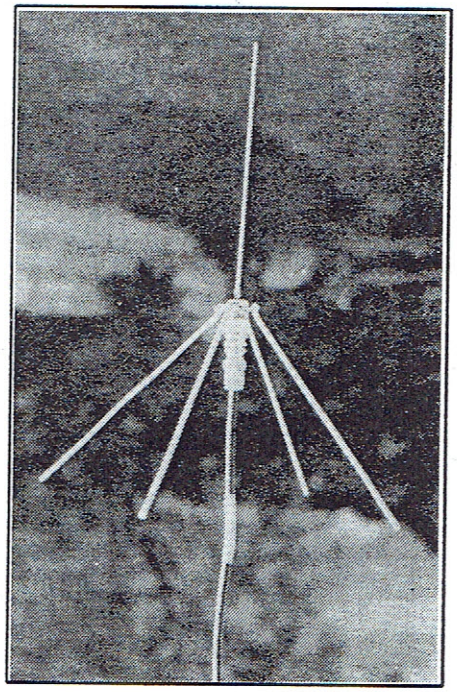

Figure 3. Groundplane antenna designed for Russian LEO NAVSAT reception.

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inch element into the tube on the top of the connector and solder them together. Then take the 1/8-inch elements and bend the last 1/4-inch on one end of each to a 45 degree angle. Insert the bent element ends into the SO-239 screw holes. Use a high wattage soldering gun to solder each element to the flange.

Although a groundplane antenna will work indoors, best results will be had if it's placed outside. Look for an outdoor location that provides a good view of the horizon, but is close enough to the scanner to require a cable run of 25 feet or less. Then mount the antenna high enough so that it clears the roof of the building.

Monitoring Techniques

There are two basic techniques for monitoring NAVSATs. The first is to program your scanner with the lower and upper frequency limits of the VHF or UHF NAVSAT band (149.905-150.035 and 399.750-400.090 MHz, respectively) and then scan the band in 5 KHz steps from top to bottom. The second method is to program your receiver's memory channels with the actual transmitted and adjacent frequencies [9] (Table 3). Although the receiving mode isn't critical, VHF signals are best heard using FM narrow, whereas AM works best for the UHF transmissions. Regardless of the monitoring technique you use, be sure set the squelch for maximum sensitivity by rotatating the squelch control on your scanner fully counter-clockwise and then clockwise until the noise barely stops.

What You'll Hear

The VHF signals will sound like a series of rapid musical tones (the position data) accompanied by a "tink...tink... tink" (the time pulses). The UHF signals have no sound; they're simply dead carriers. During a typical pass, VHF and UHF signals will slowly fade in and out. If you monitor these satellite bands long enough, you'll also hear other satellites as well, most of which are operated by the U.S. military.

Conclusion

The Russian LEO NAVSAT systems have provided naval and merchant marine users with navigational information for three decades. The VHF and UHF signals from these satellites are easily heard using simple equipment and provide scanner enthusiasts with an easy introduction to satellite monitoring.

Table 3. Frequencies (MHz) for Monitoring Russian LEO NAVSATS.

149.905	149.975	399.755	399.850	400.000
149.910	149.995	399.760	399.910	400.005
149.915	150.000	399.765	399.915	400.010
149.935	150.005	399.770	399.920	400.070
149.940	150.025	399.830	399.925	400.075
149.945	150.030	399.835	399.930	400.080
149.965	150.035	399.840	399.990	400.085
49.970	399.750	399.845	399.995	400.090

Table includes actual transmitter frequencies and frequencies on which signals will be heard due to Doppler shift.

Notes

1 The spacing, in degrees of longitude, of the points at which NAVSAT orbits the cross the equator.

2 This suggests that some users have the ability to use both the military and civilian systems.

3 This statement was apparently provided by the Russians in an effort to minimize the area of operations of their navy. The Russian navy and merchant marine operate far from Russian waters and both the military and civilian LEO NAVSAT systems are capable of providing global coverage.

4 The signals from distress beacons are received by the satellite and relayed to several control centers on the ground.

5 These satellites orbit above the ionosphere which bends the signals. This refraction needs to be measured and compensated for in order to obtain maximum accuracy.

6 The procedure described here is how a user would manually determine his position. Fixes are probably all obtained automatically using special receivers which receive the signals, perform the computations, and display the user's coordinates.

7 Data is sent in a frame that lasts one minute. Each frame is divided into two sets of four blocks. Each block has seven words. The data includes Moscow Time in hours, minutes, and seconds; orbital information for the transmitting satellite, and orbital data for other satellites in the system.

8 Brass brazing rods are available from welding supply shops and some hardware stores.

9 This is done because of the Doppler shift.

Acknowledgments

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